Strength and Corrosion Testing of Jute/ Glass- Epoxy Hybrid Composite Laminates

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Abstract

Three ply and five ply composite laminates of jute/glass-epoxy have been prepared by hand moulding technique. Tensile strength at fracture has been determined experimentally and compared to that of theoretical values. Moisture absorption capacity for both the specimens has been found out by hygrometric principle. Corrosion tests have also been carried out by experimental set up developed in house at a low cost referring to the standard ASTM B117. It has been observed that the deviation for strength of composites from theoretical values particularly for 3-ply (70%) is much more compared to that of 5-ply laminate (2%). Moisture absorption capacity of both the composites is found to be excellent (within 1.28%). Corrosion testing in 10% brine solution indicated oxidation after 24-30 hours of testing which has been justified due to gain in weight measured by gravimetric principle.

Keywords

Jute/Glass-Epoxy Laminates; Tensile Strength; Moisture Absorption and Corrosion Tests

Introduction

In recent times, light weight and high strength materials have been developed owing to soaring demands from industries and domestic applications. Most of the components of automobiles, aerospace, domestic appliances and packaging industries need waterproof, reasonably good strength and corrosion resistant materials to fight against environmental attack. Interior decorative materials, furnitures and fittings are also to be developed for better asthetic values. Under such circumstances, it is no doubt that polymeric composites play a very important role in such applications due to its light weight, high strength, moisture, crack and corrosion resistant properties. Therefore an attempt has been made in the present investigation to develop hybrid composite laminates of jute/glass-epoxy to satisfy the above needs. The strength, moisture absorption capacity and resistance to corrosion in saline environment are studied in this investigation. Further in order to develop composites with better mechanical properties and environmental performances, it is necessary to impart hydrophobicity to the fibres by chemical reaction with suitable coupling agents or by coating with appropriate resin. Apart from much lower cost and little energy requirement on the production of jute (only 2% of that for glass) makes it attractive as a reinforcing fibre in composites. The jute composites are used in lamp shed, suitcase, paperweight, helmets, shower and bath units as well as for cover of electrical appliances, pipes, post-boxes, roof-tiles, panels for partition & bio-gas containers and in the construction of low cost mobile and prefabricated building which can be used in cases of natural calamities. Under such circumstances, it has been thought proper to develop a hybrid composite of jute-glass-epoxy composite to find out the mechanical strength, moisture absorption capacity and corrosion resistance etc. ASTM offers a complementary classification of corrosion that can be useful for designers. This classification categorizes various corrosion processes by mechanism of attack. Inspection of this indicates that some forms of corrosion affect large areas while other mechanisms are very local in nature. In many cases, corrosion is the life-limiting factor of a component. Corrosive failure can occur unexpectedly at the worst possible moment. Under right conditions, accelerated testing may yield data beneficial in selecting the most corrosion resistant material for an application. Effective corrosion control requires meaningful test data in a reasonable time frame such

that it may be employed to influence material selection and protection effort.

Review of Literature

The composite technology of polymeric matrix reinforced with man made fibers such as glass, Kevlar, carbonates has matured especially with the advances in aerospace application since 1950. Sridhar et al. studied the mechanical properties of jute/polyester fibre and concluded that the jute/polyester composites are highly flexible, highly resilient, low shrinkage property, very good resistance to weather, good chemical resistance and fire resistance properties. Rao et al. studied the effect of fibre volume fraction in jute-epoxy and glass-epoxy composite on moisture absorption and concluded that jute-epoxy composite is more prone to moisture than glass-epoxy composite. Mohan et al. observed that reinforcement of glass or jute fibres with epoxy base has considerably increased the flexural properties and moisture absorption capacity. Baboian and Robert described the accelerated corrosion testing of composites after prolonged period of exposure to saline environment by gravimetric principle. There are 15 ASTM standards on controlled humidity tests alone. Moreover, each test includes a range of test conditions. ASTM B 117 allows the concentration solution to range from 3.5% to 20%. Basak et al. who studied the properties of jute reinforced composite by treating them through chemical solutionsy treated jute with tri-isostearoyl titanate, g-aminopropyl trimethoxy silane, sebacoyl chloride, and toluene di-isocyanate to increase the hydrophobic properties of jute. Sangeeta and Biswas studied the mechanical properties of jute & glass fibre by taking different ply of jute/glass composites. Elastic properties of jute/glass epoxy composite have been studied by Sabeel Ahmed and Vijayrangan. The results indicated that Youngs modulus of laminates was increased in both wrap and weft direction for glass reinforced polyster composites where as Poisson's ratio decreased. The deviation between theoretical and experimental data was about 20%. The hybrid composite of jute-glass and epoxy showed insensitive at high loading rate as indicated by Srivastav et al. But UV treated samples have shown better yield results than untreated ones. Hydrolytic stability of the composites was tested against water, 10% aq. HCl and NaCl solutions at 35°C and also in boiling water by Bhuva and Parsania. The percentage of water uptake, equilibrium time, and diffusivity of the composites has been determined and their possible applications have also been discussed. The flexural, electric and tensile strengths have also been determined. A comparison of properties between glass-epoxy-fly ash and fly ash-epoxy composite has been made by Singla and Chawla. Compression and impact tests have been carried out with varying weight fractions of fly ash and glass reinforcements in epoxy. SEM has been done to analyze the fractured surfaces. Chemical resistance to acids, alkalis and solvents to jute-glas and varying weight fractions of silica filled composites have been analyzed by M. Ashok kumar and K.Madhu. It was concluded that all the composites have shown better chemical resistance to acids and alkalis except toluene. Impact and hardness properties of areca filled epoxy composites have been determined by Srinivasa and Bharath. Treated Areca-epoxy (60-40) has shown better results compared to others. Girisha et al. have studied the mechanical performance of natural fibre reinforced (NaOH alkali treated) hybrid composites. Tamarind fruit fibre and Arecanut fibres were reinforced to epoxy. For treated fibres, it was observed that tensile strength and flexural strength have increased with the increment in fibre volume fractions. However, beyond 40% reinforcement the strength has decreased. Impact properties of 50% reinforced composite has yielded the best result. Sahoo et al. investigated the performance of resin impregnated non-oven jute felt reinforced composites (veneer) in comparison to the natural wooden core ply wood. After prolonged period of testing for physio-mechanical properties, it was observed that this material can be a substitute to normal ply wood.

Objectives

- Fabrication of hybrid composite laminate (3 ply & 5 ply) of Jute/Glass fabric reinforced with epoxy resin.
- Determination of tensile strength at fracture of prepared composites by Tensometer.
- Determination of moisture absorption capacity of prepared composite by hygrometric principle.
- Determination of corrosion resistance of prepared composites by gravimetric principle to develop a test rig in-house.

Theoretical Analysis

The composite specimens are prepared based on their weight fractions and volume fractions. In the present investigation, it has been proposed that these fractions with limitation of 10-15 % were varied and the specimens were prepared accordingly. However, the laminates have been prepared by taking fabric mats (both jute and E-glass) of 300x300 mm size and wetting it with appropriate amount of epoxy.

TABLE 1 – MECHANICAL PROPERTIES OF JUTE, GLASS FIBRE AND EPOXY

Properties	Jute	Glass	Epoxy
Density (gm/cc)	1.3	2.5	1.08-1.2
Young's modulus (MN/m2)	72	55.5	3.7GPa
Moisture absorption after 24 hrs (%)	6.9	0.5	-
Aspect ratio	152-365	100-140	-
Specific gravity (gm/cc)	1.3	2.5	1.08
Tensile strength (MN/m2)	3400	442	85
Specific modulus (GN/m2)	28.8	42.7	

Nomenclature

E_{fJ}=Young's Modulus of jute fibre, E_{fg}=Young's Modulus of glass fibre, E_m=Young's Modulus of matrix, E_c =Young's Modulus of composite, V_{fJ}=Volume of jute fibre, V_{fg}=Volume of glass fibre, V_m =Volume of matrix, v_{fJ}=Volume fraction of jute fibre, v_{fg} =Volume fraction of glass fibre, v_m=Volume fraction of matrix, W_{fJ}=Weight of jute fibre, W_{fg}=Weight of glass fibre, W_m=Weight of matrix, w_{fJ}=Weight fraction of jute fibre, w_{fg}=Weight fraction of glass fibre, w_m=Weight fraction of matrix, ρ_{fl} =Density of jute fibre, ρ_{fg} =Density of glass fibre, ρ_m = Density of matrix, ρ_c = Density Composite, σ_{fj} =Tensile strength of jute fibre, σ_{fg} =Tensile strength of glass fibre, σ_m =Tensile strength of matrix, σ_c =Tensile strength of composite

Theoretical Calculations of Strength

Weight fraction of jute fibre w_{fJ} =$W_{fJ}/(W_{fJ}+W_{fg}+W_m)$, Weight fraction of glass fibre w_{fg}=$W_{fg}/(W_{fJ}+W_{fg}+W_m)$, Weight fraction of matrix w_m=$W_m/(W_{fJ}+W_{fg}+W_m)$, Volume fraction of jute fibre v_{fJ}=$V_{fJ}/(V_{fj}+V_{fg}+V_m)$, Volume fraction of glass fibre v_{fg}=$V_{fg}/(V_{fJ}+V_{fg}+V_m)$, Volume fraction of total fibre v_{ft} =$v_{fJ}+v_{fg}$, Young's modulus of mixture E_c=E_1*v_{ft} + E_m *v_m, Tensile strength of mixture $\sigma_c = \sigma_1 * v_{ft} + \sigma_m * v_m$, Where

$\sigma_1 = \sigma_{fj} * v_{fj} + \sigma_{fg} * v_{fg}$ and $E_1 = E_{fj} * v_{fj} + E_{fg} * v_{fg}$

TABLE 2 THEORETICAL ENGINEERING PROPERTIES OF COMPOSITE LAMINATES

Sample	v_{fJ} (%)	v_{fg} (%)	v_m (%)	w_{fJ} (%)	w_{fg} (%)	w_m (%)	E_c (GPa)	σ_c in (MN/m²)
S-1	9.18	5.04	85.78	10.15	10.72	79.13	3.17	53.34
S-2	8.52	5.84	85.64	9.37	12.35	78.28	3.169	51.08

Experimental Investigations

Hand moulding technique was applied to manufacturing of the 3-ply as well as 5-ply hybrid composite laminates. Epoxy CY230 and Hardner-HY951 (Hindustan Ciba Geigy) were mixed in a ratio of 5:1. Mylar sheets were used as a mould-releasing agent. Woven jute and glass fabrics (E-Mat) were taken as reinforcements. Then the glass fibre was placed in between two jute fabric mats of one square foot size in 3-ply and for 5-ply laminate alternate jute and glass fabrics were placed. The mats were completely wetted by epoxy resin. By using rollers (20Kg), rolling was done on Mylar sheets to remove voids. The composite laminate was kept for 24 hours for curing at room temperature under application of pressure by dead weights (5Kg each- 4 nos.). Then the Mylar sheets were detached and the composite laminates were removed. Similar procedure was applied to 5-ply hybrid composite laminates.

Two pairs of specimens were prepared both from 5-ply and 3-ply of dog-bone shape as shown in Fig.1. Dimensions of specimens were taken according to ASTM standard as shown in Fig.2. The deviations of specimen from the standard specimen are as shown in Table 3. The specimens are subjected to testing in Tensometer (MIKROTECH, 2T Capacity, A Kudale Enterprise, Load ranges- 2000, 1000, 500,250, 125, 62.5, 31.25, 16,and 8 Kgf)) as shown in Fig.3. A load range of 16 Kgf was set for the

experiment. Then the calculated value of Tensile strength and Young's modulus was compared with that of the theoretical values.

FIG.1 HYBRID COMPOSITE SPECIMENS AS PER ASTM STANDARD

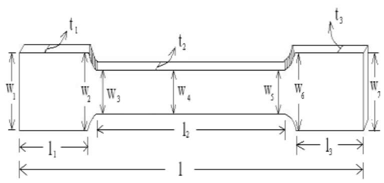

FIG.2 SCHEMATIC DIAGRAM OF STANDARD SPECIMEN

FIG. 3 TENSOMETER LOADED WITH SPECIMEN

FIG.4 SPECIMENS FOR MOISTURE ABSORPTION CAPACITY TEST

TABLE 3 DIMENSIONS OF PREPARED SPECIMENS (MM)

Specimen	l_1	l_2	l_3	l	w_1	w_2	w_3	w_4	w_5	w_6	w_7	t_1	t_2	t_3
Standard	42	100	42	204	25	25	13	13	13	25	25	-	-	-
Variation of 5-ply dimension from standard dimension														
Sp-1	0.1	0.2	0.0	24	1.0	0.8	0.2	0.7	0.5	0.2	**0.1**	**-**	**-**	**-**
Sp-2	0.1	0.9	0.5	15	1.3	1.0	0.8	1.0	1.0	0.8	**0.8**	**-**	**-**	**-**
Variation of 3-ply dimension from standard dimension														
Sp-1	0.2	1.0	1.0	26	0.7	0.5	0.3	0.4	0.0	0.0	0.0	-	-	-
Sp-2	0.2	1.0	0.8	44	2.0	2.3	1.7	1.0	0.7	0.2	0.0	-	-	-

Results of Tensile Tests

The tensile strength of prepared specimens was carried out by Tensometer and the obtained results are interpreted as shown in Table 4.

TABLE 4 RESULT INTERPRETATION

Specimen	Theoretical value of σc (MPa)	Experimental value of σc (MPa)	Deviation in MPa
Sp-1 (3-ply)	53.34	16.93	36.41
Sp-2 (5-ply)	51.08	49.97	1.11

The deviation of the experimental value from the theoretical value is probably due to the following reasons;

- There may be presence of voids which have weakened the specimen.
- There may be crack propagation during the specimen preparation.
- There may be some variations in dimension which results in non uniform force distribution.
- Due to improper gripping, the force may not act in the center line which could not be detected using a micrometer.

Moisture Absorption Capacity Tests

For moisture absorption capacity test disc type specimens were prepared with standard size (50 mm diameter and thickness 4 mm for 5-ply and 2.5 mm for 3-ply laminate) according to ASTM standard. Two specimens were prepared from 3-ply as well as 5-ply hybrid composites as shown in Fig.4. The dry weight of both specimens was taken by an electronic balance. Then specimens were allowed to soak in the water for 24 hours. After that the specimens were taken out and clotting papers were used to absorb extra water contents on the outward surface. Then the weights were noted down and the gain in weight was calculated as shown in Table 5.

TABLE 5 EXPERIMENTAL VALUES OF MOISTURE ABSORPTION CAPACITY

Specimen	Diameter in mm	Thickness in mm	Dry weight in gm	Weight after soaking for 24 hours	Gain in weight in gm	Moisture absorption capacity in %
Sp-1 (5-ply	49.5	4	9.126	9.243	0.117	1.28
Sp-2 (3-ply)	50.3	2.5	6.131	6.206	0.075	1.22

Corrosion Testing

Typically, all conventional corrosion testing is and time consuming expensive. There are three major types of corrosion tests: Laboratory, Field, and Service testing. Naturally, service testing provides the highest fidelity results followed by field testing. However, the service and field tests have limited prospects for accelerated testing. Accelerated corrosion testing becomes increasingly more realistic as the laboratory environment approaches that of the service environment. To account for the variation of corrosion types, such as uniform attack, pitting, stress corrosion, and crevice corrosion, before implementing any corrosion test, care must be taken in the selection of the corrosive media and preparing the test specimen. The onset of corrosion may seriously aggravate damage in an entirely unpredictable manner. Caution must be exercised to make certain that the corrosion mechanism is not altered. Accelerated tests are typically qualitative, and the information obtained from them is best used to down-select the most appropriate materials for use in specific application. In the present work, a test set up has been developed in house conforming to the ASTM standards B117.

Experimental Set-up

A cylindrical cabinet of radius 203.2 mm and height 457.2 mm is clamped to a heater (1000 watt) at the base as shown in Fig.5. All instrumentation and controls are grouped on a conveniently positioned cylindrical cover at the top of the cabinet, which enables the status to be monitored at any instance and conditions to be adjusted as needed. The instrumentation and control includes a pressure gauge and a thermometer. Using potentiometric principle a variac is connected to heater terminals thereby making it a closed circuit.

Three pairs of test specimens were prepared from 3-ply as well as 5-ply hybrid composites. The specimens are of square size of dimension 1 inch or 2.5 cm. Three pieces of 3-ply and 5-ply hybrid composites were suspended within the cabinet by hanging wires as shown in Fig.6. The cylinder was filled to a certain extent with saline waters of concentration 10% of NaCl. Power supply was provided through variac and adjusted to make the temperature within the range of 40~45^{0}C. The pressure gauge reading throughout the experiment was maintained at 1 kg/cm^2. After a period of 24, 28 and 30 hours, the weights of the specimens were taken. The experiment care has been taken so as to maintain the temperature within that range. The weight loss indicates reduction and weight gain confirms oxidation. The results from specimens under test are interpreted in Tables 6, 7 8 and 9.

FIG.5 EXPERIMENTAL SETUP OF CORROSION TESTING

FIG.6 SPECIMEN UNDER TESTING

Key Features of Corrosion Test Set-up

1. Ideally suited to test small components or where laboratory space is limited.
2. Allows salt spray to be continuously collected and measured without the need to open the cabinet roof and interrupt the test.
3. Ensures a rapid rise to set temperature and a uniformly heated environment without exposure of the heaters to the highly corrosive cabinet environment.

TABLE 6 WEIGHTS OF SPECIMENS AFTER 24 H OURS

Specimen (5-ply)	Dry weight in gm	Final weight in gm	Weight gain in gm	Specimen (3-ply)	Dry weight in gm	Final weight in gm	Weight gain in gm
Sp-1	2.784	2.921	0.137	Sp-1	1.468	1.544	0.076
Sp-2	2.805	2.936	0.131	Sp-2	1.829	1.919	0.09
Sp-3	2.476	2.604	0.128	Sp-3	2.215	2.286	0.071

TABLE 7 WEIGHTS OF SPECIMENS AFTER 28 HOURS

Specimen (5-ply)	Dry weight in gm	Final weight in gm	Weight gain in gm	Specimen (3-ply)	Dry weight in gm	Final weight in gm	Weight gain in gm
Sp-1	2.784	2.912	0.128	Sp-1	1.468	1.533	0.065
Sp-2	2.805	2.929	0.124	Sp-2	1.829	1.913	0.084
Sp-3	2.476	2.591	0.115	Sp-3	2.215	2.283	0.068

TABLE 8 WEIGHTS OF SPECIMENS AFTER 30 HOURS

Specimen (5-ply)	Dry weight in gm	Final weight in gm	Weight gain in gm	Specimen (3-ply)	Dry weight in gm	Final weight in gm	Weight gain in gm
Sp-1	2.784	2.916	0.132	Sp-1	1.468	1.537	0.069
Sp-2	2.805	2.932	0.127	Sp-2	1.829	1.916	0.087
Sp-3	2.476	2.593	0.117	Sp-3	2.215	2.285	0.07

TABLE 9 RESULTS OF CORROSION TESTING (WEIGHT LOSS/GAIN)

5-ply (Sp-1)	Weight gain in gm	3-ply (Sp-1)	Weight gain in gm
After 24 hours	0.137	After 24 hours	0.076
After 28 hours	0.128	After 28 hours	0.065
After 30 hours	0.132	After 30 hours	0.069

Conclusions

It has been observed that the strength of 3-ply composite is much less compared to that of the theoretical value for which probable reasons have already been explained. However, 5-ply laminate exhibited better result as far as strength is concerned. The deviation is only 2% from the theoretical value. Moisture absorption capacities of prepared composites have been calculated by hygrometric principle. It was found to be 1.28% for 5-ply laminate and 1.22% for 3-ply laminate. Hence due to negligible moisture absorption capacity, these composites can be used in interior house decorations, food packing material, shower and bath units etc. Corrosion resistance test was conducted taking different time gap but of same concentration of brine solution. Based on analysis on the result, it can be well predicted that the jute-glass epoxy composite underwent reduction for a small period of time initially and then oxidation. These changes inferred from results suggested that these composites may not be fully suitable for use in marine environment, but this research has been conducted in controlled atmospheres on the localized environmental conditions in order to provide the basis for the development of realistic accelerated corrosion. Effective corrosion control requires meaningful test data in a reasonable time frame such that it may be employed to influence materials selection and protection efforts. The future scope of this project will make different concentrations of brine solution for the same period of time or prolonged periods.

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